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PLANNING FOR ENVIRONMENTAL INDICES

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PLANNING FOR ENVIRONMENTAL INDICES

A Report of the
Planning Committee on Environmental Indices

to the
Environmental Studies Board

of the
Commission on Natural Resources

of the
National Research Council

at the request of and funded by
The Council on Environmental Quality
The Social and Economics Statistics Administration,
Department of Commerce
The Geological Survey, Department of Interior
The Environmental Protection Agency

National Academy of Sciences

Washington, D. C.
February 1975

This report is submitted in fulfillment of contract EQC 326 between the National Academy of Sciences and the Council on Environmental Quality

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PREFACE

The Environmental Studies Board has for some time viewed the development of methods for evaluating changes in environmental quality as an important step toward rational management of the environment. The first formal Board publication, "Institutions for Effective Management of the Environment," published in January 1970, recommended strongly that a comprehensive federal program for the monitoring and evaluation of environmental quality be initiated and assigned high priority. Yet, a recent Library of Congress report has underscored that little progress in the development of indices as a means of evaluating environmental quality has been achieved. The Board therefore assembled a 13-member multi-disciplinary committee to consider a number of important factors related to environmental indices. The committee merged talents from such diverse fields as conservation, federal, state and local government administration, health, law, and psychology; as well as technical fields directly related to the environment. The group met and deliberated three times for a total of six days in November, 1973, and April and July, 1974. This report resulted from these deliberations. It has been reviewed by the Board and other qualified individuals.

The Environmental Studies Board is publishing this report in the interest of accelerating progress toward the development of environmental indices. It is the Board's view that further vigorous efforts should be exerted to develop a broad range of environmental indices, but that early results should not be expected in some areas. The Board gratefully acknowledges the financial support of the study by the Council on Environmental Quality, the Social and Economic Statistics Administration of the Department of Commerce, the United States Geological Survey of the Department of the Interior and the Environmental Protection Agency.

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1.0 INTRODUCTION

1.1 Need for this Study

Through the National Environmental Policy Act of 1969, Congress issued a mandate for the development of methods for evaluating environmental quality. Specifically, Section 102(2) (B) directs all agencies of the federal government to "...identify and develop methods and procedures, in consultation with the Council on Environmental Quality...which will ensure that presently unquantified environmental amenities and values may be given appropriate consideration in decision-making along with economic and technical considerations." In Section 204, the act further directs the CEQ to "gather timely and authoritative information concerning the conditions and trends in the quality of the environment, both current and prospective;" (and) "to document and define changes in the natural environment...."

Environmental indices are means for assimilating information about one or more aspects of the environment. Their purposes are to enhance communication and to facilitate the judgment and decision-making processes. Environmental indices are potentially powerful tools for highlighting significant environmental conditions, illustrating major trends, formulating environmental goals, and measuring progress toward these goals. They can be useful in devising environmental control programs and determining their success, both prospectively and retrospectively. Indices can be effective in defining alternatives, assessing trade-offs, constructing environmental impact statements, and informing laymen and professionals alike about the status of environmental quality. Yet, a recent report of the Congressional Research Service of the Library of Congress has observed that little progress in the

construction or use of indices has been achieved to date, primarily due to a seeming lack of interest by the relevant federal agencies. *

The objectives of the present planning study were two-fold: first, to examine the important multi-disciplinary considerations related to environmental indices, as cited below; second, to formulate conclusions and recommendations concerning development of these indices.

1.2 Scope of Committee Action

A number of topics were considered during the course of this study. These include:

(i) Requirements for formulating and implementing indices.

(ii) Potential uses and users of environmental indices.

(iii) Difficulties and cautions related to the development and application of environmental indices.

(iv) Current status of selected indices, including ones in various stages of development.

(v) Needs for future work, including supportive research and development.

(vi) Rationales for structuring a national effort aimed at developing, systematizing,and implementing environmental indices.

1.3 Organization of the Report

The report comprises five chapters. Following the Introduction, Chapter 2 contains a summary and discussion of conclusions and recommendations. Chapter 3 discusses definitions and types of indices, requirements for constructing useful indices, and potential applications. Chapter 4 presents examples of indices that represent various stages of development and utility. Finally, Chapter 5 contains a bibliography of pertinent literature.

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* "National Environmental Policy Act of 1969. Environmental Indices - Status of Development Pursuant to Sections 102(2)(B) and 204 of the Act," Committee on Interior and Insular Affairs, United States Senate, December 1973.

2.0 SUMMARY, DISCUSSION AND IMPLEMENTATION OF CONCLUSIONS AND RECOMMENDATIONS

2.1 Summary

2.1.1. A Program for Environmental Indices.

1. *A program to develop and use environmental indices (EI) should begin immediately. The Congress and the Executive should assure that this effort is implemented by directing and encouraging adequate programs and by providing appropriate stimuli and resources.*
2. *Development and use of EI should be the function of governmental agencies having the requisite expertise. As already mandated by the NEPA, the CEQ should coordinate the federal effort and should foster an understanding of the importance of EI in the legislative and executive branches of government. The CEQ should use EI in reporting the status and trends of environmental quality and should begin immediately to issue annual referenced compendia of environmental statistics.*
3. *A non-governmental Advisory Committee on Environmental Indices reporting to the CEQ should be created to establish guidelines for the development of EI. The primary function of this Committee would be to assist the appropriate agencies to develop systems of EI and to provide recommendations from the scientific community and user groups on how to utilize current information and capabilities.*

2.1.2. The Purpose of Environmental Indices.

4. An environmental index is derived from quantitative understanding of the relationships between technological change and environmental factors, and from data provided by monitoring systems. *Knowledge of the effects of environmental stress and the quality of monitoring data should be improved in any event and will thus also increase the usefulness and utility of EI derived from such information.*

5. Environmental indices provide an important method for evaluating the state of the environment. Despite strong statements of need from all three branches of government, progress toward the development and use of methods for evaluating environmental quality has not been satisfactory.

6. Systematic development and refinement of EI are needed to:

   (i) assist in formulating policy;

   (ii) provide a means for judging the effectiveness of environmental protection programs;

   (iii) assist in designing these programs;

   (iv) facilitate communications with the public concerning conditions of the environment and progress towards its enhancement.

2.1.3. The Current Status of Environmental Indices.

7. Considerable effort has been devoted to the design of air quality indices, and several systems have been proposed. *The Committee recommends that a uniform national system of air quality indices be developed and adopted. The EPA appears to be the appropriate agency to have operational responsibility for EI concerning air and water quality.*

8. There have been fewer attempts to construct water quality indices than air quality indices, despite the importance of the nation's water pollution control program. There appear to be no insurmountable obstacles to development of useful water quality indices and *the Committee recommends their prompt construction and use.*

9. No satisfactory framework exists on which to construct indices of desirable land use. This inadequacy is due to the lack of understanding about the relationships between scientific descriptions of land, various uses for land and environmental quality. The absence of a national policy on land use has inhibited definitional work in this area.

10. It is feasible now to initiate a useful system of EI that treat various specific aspects of environmental quality. While it is not certain that a single overall index of environmental quality is desirable as a long-term goal, it is certain that development of such an index in a meaningful manner is not possible at the present time.

2.2 Discussion of Conclusions and Recommendations

The Committee has concluded that the development of EI is an important and urgent matter. Indices are needed now for a variety of reasons, and the need for indices will become increasingly apparent and pressing in future years. A useful system of EI can and should be

initiated now. Programs to use existing indices and to develop additional EI should begin immediately. Thus, both short- and long-term goals can be identified for the development of environmental indices.

2.2.1. Short-Term Goals. As some of the examples in this report make clear, the data and scientific knowledge necessary for satisfactory indices are lacking in many environmental areas, but sufficient data and knowledge do exist to formulate useful indices for many aspects of the environment. Initially the construction of indices may be crude, but their use would represent an improvement over the current lack of comprehensible information for planning and evaluation.

To be most effective, the initial effort should concentrate on a few aspects of the environment and should be implemented within a reasonable time period, such as three years. Air and water quality merit high priority for initial consideration. These two areas are the subject of the most intensive and expensive control programs, and they are areas in which meaningful indices are feasible. Experience gained in designing programs to develop indices in these areas should be valuable in developing similar programs in other environmental areas.

A study should be undertaken immediately to provide indices of air and water quality. The study should address the issues discussed at length in this planning report and specifically should deal with the following questions:

(i) What indices are required?

(ii) Which of these can be developed on the basis of information now available?

(iii) Are the existing monitoring programs adequate, and if not, what changes should be recommended?

(iv) What research programs are needed to provide the additional information needed to develop an adequate system of EI?

While indices of air and water quality deserve a high priority for obvious reasons, studies should be initiated to develop other indices as well. Land use is a perplexing area where a task group could usefully begin development of a conceptual framework to design indices.

2.2.2. Long-Term Goals. It should also be understood that while tangible benefits will be realized within the first few years of an indexing program, a comprehensive system of indices will take much longer to evolve. However, the environmental problems of our nation will be with us for a long time, and the indices will become more acutely necessary as time goes on. A system of environmental indices would have been useful in the mid-60s, it would be valuable now in the mid-70s, and it will be no less necessary a decade hence.

For the long term, non-traditional approaches to index development should be explored. Biological indicators, residual balances, and material flows are alternative or complementary frameworks to indices as compared to the traditional organization by environmental categories such as air, water, or land. Indices of local or regional rather than national scope are also worthy of investigation and experimentation.

A program of index development will yield collateral benefits to supplement those enumerated earlier in this report. As has been noted,

meaningful indices must be based on valid monitoring systems and an adequate foundation of scientific knowledge. In the course of developing indices, it will be necessary to examine the adequacy of the data from these sources and it will become possible to make specific recommendations to improve the effectiveness of both monitoring and research. The requirements for monitoring the environment should be subjected, however, to continued and coordinated review. Environmental monitoring is expensive, and no measurements should be made that do not contribute to more informed knowledge about the environment. What should be measured, how it should be measured, and where it should be measured are the three basic questions that will influence the design of the monitoring system. These questions can be answered better with an improved understanding of environmental relationships. A commitment to a developmental program of environmental indices thus carries a requirement to seek expanded research efforts in the environmental and health sciences.

2.3 Implementation of Recommendations

In considering the need for further work, the Committee has faced the dilemma that while major responsibility for the development of indices must rest with the operating agencies, the efforts of these agencies with respect to environmental indices have been inadequate. How can the relevant agencies be encouraged to undertake the necessary work?

2.3.1. Agency Function. The primary responsibility for providing indices must rest with the agencies that have the responsibilities for administering environmental programs and/or have appropriate environmental expertise. The data on which to base such indices, the

technical expertise to formulate them, and the greatest need to use them are within the operating agencies. Committees of outside experts and staff agencies such as CEQ can play a vital catalytic and leadership role, but they cannot realistically be expected to undertake the vast amount of work necessary for the formulation and regular promulgation of environmental indices.

2.3.2. CEQ Function. The Council on Environmental Quality is at present the major catalytic force behind index development. The Council's efforts should be continued and strengthened so that it can innovate new measurement concepts, coordinate the development of indices, and provide an important outlet for their dissemination. The Council should systematically utilize environmental indices in assessing the state-of-the-environment for its annual reports. The Council should also accept responsibility for developing an annotated and referenced compendium of environmental statistics. This project would provide information on the environment similar to that which is given for the economic area by the annual report of the Council on Economic Advisors and in the social area by the recent OMB publication "Social Indicators, 1973." It must be emphasized, however, that the Council's role should continue to be one of coordination. Only the agencies have the resources and expertise to undertake the actual work that is required to develop adequate environmental indices.

2.3.3. Advisory Committee on Environmental Quality Indices. Much of the knowledge necessary for EI development lies in the academic community and other non-governmental institutions. Additional outside stimulus would also be desirable to accelerate the federal government's

efforts in the use and development of indices. To serve as a channel for non-governmental knowledge and as a catalyst to the government, a non-governmental National Advisory Committee on Environmental Indices should be established.

Initially the advisory committee should establish a set of priorities for the aspects of environmental quality to which indices should be applied. The priorities would be based on the importance of the area and the likelihood of a useful index being developed. Air and water quality are clearly among the highest priorities. The advisory committee would then proceed, working in close cooperation with the relevant federal agencies, to develop indices which can be immediately tested and then used on a regular basis. The operating agencies would be engaged in the same task, but the interaction of the committee and the agencies should be reinforcing rather than duplicative. In the process of developing EI, the committee should identify problems or gaps in monitoring or research which impede their development, and it should recommend ways to remedy these problems. The work of the committee may initially take the form of a study; but if the committee is successful, it should become a formal body to advise the government in this field in an ongoing manner.

2.3.4. Congress and Executive. The Congress and the Executive both have a special role with respect to indices. In order to initiate programs for the development of EI, a commitment to provide the agencies and research laboratories with the resources necessary to assure success is required. The Congress and the Executive should see to it that resources are made available for both short-term and long-term goals of these programs.

2.3.5. International Efforts. The effort toward establishing environmental indices for the United States should be correlated with the activities of the United Nations Environment Programme (UNEP) to develop compatible systems for monitoring the global environment. The United States shares the direct responsibilities for that intergovernmental effort, and through the National Research Council, participates in the work of the Scientific Committee on Problems of the Environment (SCOPE) toward designing a global network of sampling stations. Development of indices will benefit from coordination with comparative efforts in other countries.

3.0 ENVIRONMENTAL INDICES: DESCRIPTION, REQUIREMENTS, APPLICATIONS, AND CAUTIONS

3.1 Description of Environmental Indices

3.1.1. Definitions. The Council on Environmental Quality defined environmental indices in its 1970 annual report as "data aggregated to provide a picture of some aspect of environmental quality." There are many types and forms of indices, and the terms "index" and "indicator" are often used interchangeably, even inconsistently. To avoid confusion, the Committee has chosen to use the terms "measure" and "index." The term "measure" will be used to denote a number that characterizes a single aspect of the environment that can be quantified directly, in contrast to an index that is derived from a mathematical operation on one or more measures. A single measure can be used as an index, but in most cases only the aggregation of several measures will lead to an index, providing a more useful representation of a given aspect of the environment.

For example, the concentration of sulfur dioxide measures one aspect of air quality, and the concentration of carbon monoxide another. Such data on individual pollutants can be converted to a simple index of air quality by comparing the measured concentration of pollutant to its ambient air quality standard. It would be desirable to go a step further and design aggregated indices of air quality by combining measures of several pollutants into indices that in the aggregate express the state of air quality generally. The nature and complexity of an index will depend on its subject, the purpose it is to serve, and the requirement that it be scientifically valid.

Economists have devised a set of measures and indices to communicate trends in the cost of living, unemployment, gross national product, and other aspects of the economy. These indices have been accepted by the public and are used effectively in decision-making processes. Social indices have also been developed. "Social Indicators, 1973," a recent report by the Office of Management and Budget, provides up-to-date indices of health, public safety, education, employment, income, housing, leisure and recreation, and population. Many of these existing indices deal with matters that are environmental in nature.

3.1.2. Goal Indices and Programmatic Indices. A distinction based on the proposed use of an index can be made between goal indices and programmatic indices. Goal indices are those that relate to broad societal goals, of which the Committee has identified three in the context of environmental quality: maximizing human well-being; conserving natural resources; and preserving natural systems. The goal indices would be designed to measure progress towards these broad objectives, even though the goals themselves may not be mutually compatible.

The goal of maximizing human well-being goes beyond environmental considerations in the narrow sense in which "environment" is normally used. However, if one interprets the term "environment" in its broadest and perhaps most valid meaning, it would be necessary to include such goals of overriding importance as avoidance of war and elimination of proverty because these scourges are part of the environment in which man lives. This report identifies the above three goals of environmental protection with full recognition that the same goals may also be the

objectives of other policies. Various national goals that are relevant to the environment may be wholly or partly in conflict. The attainment of one goal will not necessarily facilitate the attainment of another, and the accomplishment of some may even impede or preclude others.

Indices relevant to many national goals are already available--life expectancy, rates of infant mortality, sickness, absence from work, and many others for the goal of human health; and unemployment rates, per capita income, and others for the goal of economic well-being. Indices are needed for such goals as the integrity of ecosystems, conservation and utilization of resources, and others that are directed primarily toward the physical environment itself. Goal indices, if properly chosen, can be used to estimate the net effect of the variety of programs intended to achieve these same broad national goals.

Programmatic indices are those that relate to a specific program that is designed to maintain or change some aspect of the environment. The nation is currently involved in programs to reduce air and water pollution, minimize land abuse, reduce work accidents, and eliminate the hazards of consumer products, to mention only a few. These are all part of an overall desire to achieve the broader goals identified earlier. Program indices would make it possible to estimate the extent to which the objectives of these programs are being attained. Program indices must be carefully chosen for their relevance to specific aspects of the environment or to programs designed to attain goals, and they must be reassessed repeatedly as scientific knowledge and experience accumulate. For example, the progress of a program aimed at controlling

airborne toxic substances could be measured by trends in an air pollution index. While these toxic substances have an influence on human health, goal indices such as the incidence of respiratory disease or other health indices may not be used directly as a measure of the success of this air pollution program because there are other factors that affect health. The health indices could show worsening conditions even if the air pollution program were successful. It is important to know both: progress toward broad societal goals and progress toward the objectives of specific programs. Accordingly, it is important to have both goal and programmatic indices.

3.1.3. Purpose of Environmental Indices. It is apparent at this point that many types of environmental indices exist and that they deal with diverse aspects of the environment. Nevertheless, they share a common purpose: to summarize and present information in a meaningful manner so that judgments can be made, conclusions can be drawn, and decisions can be reached. It is important, therefore, that a national effort in environmental indexing include work that is directed at unifying and systematizing existing indices insofar as practical and to insure compatibility with new indices as they are developed.

3.2 Requirements for Development and Implementation of Environmental Indices

Four requirements must be satisfied for the development and application of useful indices: (1) identification of issues or policies for which technical information is required, (2) collection of adequate and accessible data, (3) formulation of valid models, and (4) proper dissemination.

It is to be emphasized that the Committee views the development of environmental indices and indexing systems as an iterative process. By taking advantage of existing indices as well as current and emerging knowledge and experience, a national effort will retain sufficient flexibility to capitalize on advances in both scientific knowledge and indexing techniques. The examples in Chapter 4 illustrate that a long term commitment is required to develop the knowledge and refine the techniques requisite to a truly satisfactory system of environmental indices.

3.2.1. Identification of Issues. The identification of environmental issues and policies for which indices are desired is crucial. The purpose of indices is to summarize and present information on a given subject so that conclusions can more readily be drawn and decisions can more readily be made. The issues and policies that the indices are to clarify must be specified before a reliable index can be constructed. Otherwise gathering, assembling, and summarizing data may become ends in themselves.

Because indices relate to issues and policies, rarely will one index serve to summarize a broad area. The consumer price index, the unemployment rate, and the gross national product are indices which give information on the nation's economy, but taken individually none is entirely satisfactory in summarizing the economy. For example, a low consumer price index and a low rate of unemployment would seem by themselves to be attributes of a healthy economy, but sometimes a lower unemployment rate can be achieved only at the expense of higher

priorities. Trade-offs may be required to achieve any given policy goad, and a set of appropriate indices is needed to provide the complete picture.

3.2.2. Data Base. The credibility of an index or indexing system depends upon the supporting data base. The data base must be designed with many factors in mind: parameters measured, accuracy of the measurements, frequency of measurement, number (and perhaps conditions) of measurements, and expense of gathering the data.

The use for which data is being collected must also be considered. For example, an evaluation of the impact of oil on the ecological health of a body of water might require more than simply a measure of the total amount of oil present. It would be important to know whether the oil is present in large clumps, or as a uniform film on the surface. Measurements of the quantity of oil, present in one form or the other, might have varying significance, depending on the use to which these data will be put. If one's purpose is to protect a lake or other body of water as a natural system, one program of observation might be required. If one's purpose is to protect the amenities of the shore line, one would design quite a different monitoring system. A third type might be designed if the purpose of the control efforts is to assure the potability of a water supply.

The data base should be constructed with an understanding of the underlying relationships, i.e., the significance of the measurements. To illustrate, various systems of monitoring water quality have been designed over the past century because it was recognized that public health depends on, among other factors the quality of water used for

human consumption and recreation. For the most part, the monitoring system that was designed by the sanitarians early in this century used coliform bacteria as a measure of fecal contamination. These organisms are present in the intestines of humans and other animals, but are not of themselves pathogenic. It might have been more scientific to look for specific pathogens, but this would have been impractical and prohibitively expensive. Thus, the standards of water quality have, to the present time, included limitations on the concentrations of coliform organisms. During the past few years, questions have arisen as to whether the coliform count should continue to be the criterion that determines whether estuarine water is fit for bathing, since there are no studies that demonstrate a relationship between coliform count and the health of bathers. There has been inadequate epidemiological research on this question, and the significance of the coliform count insofar as human health is concerned is open to question.

One point emphasized here is that environmental information is collected in large quantities for diverse purposes. Much of this information could be included in a data bank that supports an environmental indexing effort. With the advancement of knowledge about environmental relationships new more useful, indices could be formed from an old data base if that data base has been maintained adequately. A well designed data management system for environmental indexing would also benefit many other activities that require environmental information.

3.2.3. Model Formulation. The usefulness of an index depends greatly upon the manner in which measures are aggregated. Guidance can be provided by mathematical models which attempt to characterize

environmental inter-relationships in a quantitative fashion. Models need not be mathematically complicated; they may simply express the relationship between two or more factors. Much effort is being expended currently to develop models in the fields of transportation planning, ecosystem analysis, regional planning and health. The Committee believes that development of environmental indices will be facilitated by on-going modeling research.

3.2.3.1. Scaling and Weighting. An important step in modeling which is crucial to index development involves the assignment of scaling and weighting factors to environmental measures. The combination of a set of environmental measures into an index requires that each measure be scaled and weighted. Scaling means conversion to common units; weighting means that each measure be assigned a value proportional to its relative importance in determining the overall quality of the aspect of the environment being evaluated. The spread and variability as well as the scaled and weighted average of measures of environmental quality are also important. For example, for air quality it is important to know how many hours per day pollutants exceed a certain concentration as well as to know the average concentration.

Assignment of quantitative weighting factors to the individual measures presents difficult problems because of the lack, in most cases, of definitive and reliable information on cause and effect. A further complication is the probable existence of multiplicative effects, i.e., synergisms and/or antagonisms. Two pollutants acting together may cause more harm to health or property than would be estimated from the sum of the effects of the two pollutants acting alone.

One example is the suspected synergism between sulfur oxides and particulates. The stress on the human cardiorespiratory system is greater when these two pollutants are combined than from exposure to the same concentrations of each pollutant separately. However, the synergistic interaction is not yet understood quantitatively. Finally, and most importantly for many types of indices, weights are frequently dependent upon human values. The Committee recognizes both the difficulty and importance of devising appropriate weighting methods that include all of these considerations. Much attention to this aspect of environmental indexing will be a necessary part of future indexing development efforts.

In the course of aggregation, the primary measurement data need not and should not be lost. Indices should be designed so that the information they convey can be accessible for more detailed consideration when it is desirable to do so. Indices should be capable of being disaggregated as well as aggregated.

3.2.3.2. Biological Indicators. Living systems themselves are effective means for aggregating a variety of environmental factors. Organisms react directly to environmental stresses, including synergistic ones, and integrate effects through time. Direct observations of these effects along the entire biological spectrum--from subtle biochemical reactions to drastic population fluctuations in a variety of species ranging from the simplest to the most complex--may convey more information about the likely responses of other living organisms than do predictions of these responses from physical measurement or mathematical models. Plants and animals can function as early warning systems against specific insults, as well as indices of environmental quality and health

in general. The miner's canary is an obvious example. Further work to identify, classify, and use suitable biological indicators of environmental quality is warranted and should be encouraged.

3.2.4. Dissemination. The main purpose of dissemination is to encourage greater use of scientific information by the general public and special interest groups to influence environmental policy decisions. Indices of broadly defined environmental goals should be communicated to the general public on a timely basis. This type of information is needed to monitor long-term trends in environmental conditions and to carry on the political debate regarding future strategies for using and protecting the environment. The discussion of the status of and trends in the environment in the 1972 CEQ Annual Report was influential. With the release and wide distribution of the Report, the lack of appropriate information for environmental policy planning became evident. This type of reporting to the public is important because it keeps the pressure on government and the research community to make their information available and to improve the knowledge base through directed research.

Communication can take the form of annual reports to Congress by the Executive, coupled with open discussion of these materials, but indices can also be communicated through statistical compendia, budget reports, agency reports, scientific journals, and the media. The public is using this type of information more and more frequently in policy discussions.

Indicators of program performance can also be focused for general public use, but these data are of greater importance to decision-makers, in and out of government, and to those persons more intimately involved

with environmental research, monitoring, and regulation. Program evaluation is often local rather than national in scope and the results of policies and programs aimed at protecting the environment should be aimed at the appropriate administrative level. For example, research on the Chesapeake Bay region can be reported in a form most useful to the various organizations involved in influencing the environmental quality of that area. As environmental reporting develops, the concepts and methods used to measure environmental quality in different regions of the country (and in other countries also) will tend to become standardized. It will be necessary continually to refine and develop new methods for communicating these indices to intended users.

3.3 Applications of Environmental Indices

3.3.1. Communication with the General Public. A valuable application of environmental indices is to facilitate communication of environmental information to the general public which, in this context, includes highly trained people whose disciplines differ from those needed to understand fully the particular environmental aspect under consideration. A chemist, for example, may be a scientific layman to a sociologist or economist. Accordingly, indices may also serve a vital educational function. The use of indices which summarize changes in the economy has raised the whole level of political discussion about economic matters during the past quarter century. Although environmental indices may differ markedly from economic indices in their quantitative character, it can be anticipated that properly formulated environmental indices will play a similar role in environmental matters.

3.3.2. Monitoring Trends in Environmental Quality. This application was mentioned earlier and reference has been made to the need for CEQ and others to report trends in environmental quality in their annual reports. Federal, state, and local governments are currently designing environmental protection programs which involve commitments of billions of dollars. In view of the character of these commitments, the monitoring of changes in the environment will assume increasing importance with time as an aid in reviewing environmental management activities. Environmental impact statements are prime candidates for application of environmental indices.

3.3.3. Establishing Policy. It is axiomatic that policy-making involves evaluation of trade-offs and that progress toward one goal must sometimes be slowed to achieve progress toward others. Environmental indices could assist in making these evaluations. Similarly, good program planning entails the setting of priorities, which may be influenced to a great extent by political considerations. There is evidence that environmental priorities sometimes become unclear because the basis for decision-making has been far too subjective. The use of environmental indices should lend more objectivity to program planning, whether the program is oriented toward research, development, or control. Moreover, environmental indices provide an additional means for monitoring program performance and the net effectiveness of environmental programs. The key point here is that the utilization of suitable indices can foster decisions based on information that is tailored to the user's specific needs.

3.4 Cautions

The shortcomings of even well conceived environmental indices are similar to those of almost any kind of statistical data that are employed

for interpretive purposes. Indices are only as good as the data and the assumptions used to formulate them. Care must be taken, of course, to insure that they are formulated correctly and are not manipulated by a selective presentation of data to advance some preconceived position. A more serious problem, however, is that the user may neglect the assumptions made in formulating them. At least two undesirable consequences could then result: (1) the indices may limit the recognition of new problems or new knowledge; and (2) unwarranted conclusions might be drawn from the indices.

These consequences may occur because of lack of knowledge, or because the indices are directed toward some other concern. For example, the concentration of some substance present in trace quantities may not be considered in constructing a water quality index because its importance may not be recognized. Perhaps the substance may not be monitored or there may not even exist a means for reliable measurement. Yet future research may show that the substance can have significant effects on health after prolonged exposure to minute ambient concentrations. Our recent experience with the polychlorinated biphenyls (PCB) and methyl mercury are examples.

Another problem with indices is that they may obscure the importance of subjective factors, that is, of personal preferences and values. Even though aesthetic considerations are difficult to quantify, they must not be ignored or obscured in constructing indices. The need is for indices whose utility and shortcomings are understood by laymen and specialists alike. Such indices, used in a proper and thoughtful way, can be an important aid in environmental decision-making. The national

experience with economic indices suggests that when used intelligently, the utility of good indices far exceeds their shortcomings. Although the theory and construction of economic indices is different from that of environmental indices, the positive experience with economic indices provides us with a stimulus to develop similarly effective indices in environmental areas.

4.0 EXAMPLES OF ENVIRONMENTAL INDICES

Discussion here will be limited to four examples which illustrate the development and application of environmental indices for somewhat distinct facets of the environment: ionizing radiation, air quality, water quality and land use. These particular areas are of interest because they provide contrasts in the conceptualization, state-of-the-art of development, and usefulness of environmental indices. They also illustrate that the development of useful indices requires adequately funded programs and years of work. Much progress has been made in some environmental areas, but a long term commitment is needed to insure further progress and to accelerate development of indices in other areas.

4.1 Ionizing Radiation

The potential risks from ionizing radiation is an excellent example of an environmental factor for which a useful environmental index has been developed, and the evolution of the model currently used to evaluate the risk to the public will be described in some detail.

Only a few years ago, the various radionuclides present in the environment from nuclear weapons testing or reactor operation were measured individually and reported in tabular form for various parts of the country. Other estimates of human exposure were made for other sources of ionizing radiation such as the use of medical X-rays or pharmaceutical radionuclides. During the past decade, the concept evolved that the per capita dose is a valuable index that can aggregate the various sources of ionizing radiation. This simplifying assumption can be made because of the functional model that was developed to describe the effects of various kinds of ionizing radiation

on the general population. The relative biological effectiveness of the dose depends upon the type of radiation (alpha, beta, gamma, neutron, etc.) which is evaluated by the use of standard radiological dose terms. There are two major effects: (1) genetic and (2) carcinogenic. The critical site for genetic effects is the reproductive organs; for the carcinogenic effects it is usually the blood-forming tissues. It is further assumed that for purposes of defining the upper limit of risk, the dose-response curve should be assumed to be linear, without a threshold, and independent of dose rate. Finally, risk coefficients have been developed which described the number of genetic defects or the number of cancers per unit of dose per million of population. These coefficients have been derived from extensive epidemiological studies of irradiated populations on a scale that is without parallel with respect to other chemical and physical agents of disease.

There is evidence that these assumptions over-estimate the risk, but they help to provide a model that serves as a useful starting point for estimating the upper limit of risk to the population. This model has been used by the Environmental Protection Agency to estimate per capita dose rates for 1960, 1970, and, prospectively, for the year 2000. These estimates are given in Table 1. If used with a full understanding of their limitations, such estimates can serve as useful "ionizing radiation indices."

Table 1

Ionizing Radiation Dose Rate From Various Sources*

Source of exposure	Per capita dose rate (mrem/year)** 1960	1970	2000
Natural	130.0	130.0	130.0
Occupational	0.75	0.8	0.9
Nuclear Power	0.0001	0.002	0.2
Fuel reprocessing	---	0.0008	0.2
AEC activities other than open-air weapons testing	0.01	0.01	0.01
Open-air weapons testing	13.0+	4.0	4.9
TV, consumer products, air travel	1.6	2.6	1.1
Diagnostic radiology	72.0	72.0	72.0
	217.	209.	208.

*From Environmental Protection Agency (1972)
**The millirem is a unit of biological dosage related to the amount of energy deposited in tissue by various kinds of ionizing radiations.
+1963

It was necessary to complete two important steps before Table 1 could be prepared: (1) collection of basic information about the sources of radiation exposure at different places as a function of time; and (2) development of means of expressing the collected basic information on a common basis so that it could be distilled and summarized in a meaningful way.

The first process required the development of monitoring systems. However, before rational monitoring procedures could be specified, it was necessary to understand the effects of radiation on people. It was also necessary to develop instruments and standard procedures for gathering information reliably and economically.

The second process, aggregation of the collected data, was especially crucial. Ionizing radiations exist in many different forms, including beta and gamma rays and alpha and neutron particles. Models for describing the mechanisms by which these ionizing radiations affect biological systems were hypothesized and subjected to experimental scientific investigations. Scientific research conducted over many years allowed the development of a simple model which offered a practical means of comparing and evaluating the biological impact of different types of radiation, whether natural or man-produced. Only by this research effort could the model and its attendent assumptions be justified, enabling one to put the subject of radiation effects into quantitative terms. Progress with respect to ionizing radiations became possible because of efforts to the Atomic Energy Commission and other agencies spanning nearly three decades and involving the expenditure of hundreds of millions of dollars.

The dose rates listed in Table 1 are, therefore, indices of potential effects on human health and can serve in the formulation of national policies designed to reduce exposure of the public to various sources of radiation. The per capita radiation dose rate from nuclear power plants averages a fraction of a millirem per year and is expected to be relatively small even in the year 2000, whereas the dose from the medical uses of the ionizing radiations is and will continue to be much higher. The data suggest that radiation exposure can best be reduced by controlling such exposure from medical practice. The low priority that has been given to controlling medical radiation exposures is one indication that the information contained in Table 1 is not being disseminated effectively. Not only is a concerted effort required to investigate, assemble and organize the information required to develop an index, but a mechanism for disseminating the index is required if the index is to be useful and relevant for policy decisions.

Limitations of the radiations indices are also apparent. The estimates given in Table 1 suggest that radiation exposures from nuclear power plants might average a fraction of a millirem per year by the year 2000 if averaged over the entire population. However, Table 1 deals with the normal plant operation and does not take into consideration the possibility of a catastrophic accident. The values in Table 1 could not be used to develop estimates of radiation exposure under the assumption that a nuclear catastrophy occurred. Thus, index values cannot be accepted blindly; the underlying assumptions must be clearly understood.

4.2 Air Quality

Many urban residents are more concerned with air quality than any other environmental feature. Regular reporting of some type of air

quality index, usually simplistic, is common on radio, television, and in the press in some of the large cities.

The issues and policies for which air pollution indices are required are similar to those associated with ionizing radiation. Ideally, air quality indices would provide information on the concentration of pollutants in the air; the health, ecological, economic, and aesthetic effects of air pollution, as well as the sources of pollution; and the efforts expended toward abatement. Air quality indices are less well developed than those for ionizing radiation because monitoring air pollution and evaluating the health, ecological, and aesthetic effects of air pollution are intrinsically more difficult and also because there has been much less research on the subject. Nevertheless, much has been accomplished.

A rather extensive nationwide network of air pollution monitoring sites exists. Instruments and methods have been developed to measure routinely a number of air pollutants including carbon monoxide, oxides of nitrogen, oxidants, sulfur dioxide and particulate matter. However, only sulfur dioxide and particulate matter are routinely monitored in most places, the number of monitoring sites is often inadequate, and they are not always located to provide representative information. While the basic data-gathering is deficient in many respects, the committee believes it is adequate for the development of some indices.

A number of indexing schemes have been devised and promulgated during the past several years. These have been devised either locally for local use or under a federally-sponsored contract for more general use. Because most of them were developed locally, there now exists a

multitude of air quality indices--some good and some bad--but none so outstanding as to gain wide acceptability. A systematic appriasal of the available air quality indices is needed for the purpose of introducing uniformity.

Most air quality indices, whether they be local or national in scope, rely on the two classes of federal ambient air quality standards. The primary standards are those which are designed to protect the public health, whereas the more stringent secondary standards are intended to protect materials, vegetation, and the amenities. These standards have been used to provide a basis for aggregating the major air pollutants for indexing purposes, but there are many air pollutants for which there are as yet no federal standards.

Aggregation of air quality measures into an index is generally accomplished by dividing the measured ambient air pollutant levels by the federal standard for each pollutant (scaling), weighting these ratios according to importance, and then arithmetically or geometrically averaging the ratios. A major practical difficulty here is that the time intervals specified in the federal standards are not uniform and do not in fact agree with the time intervals usually used to collect data on pollutant concentrations. A more severe problem is that the relative importance or weights given to the several pollutants are assigned arbitrarily in most instances. A third problem, particularly insofar as communication with the general public is concerned, is that adjective descriptors are not used with most index values (or they are misunderstood). The general public wants to know what an air quality rating of 55 means--is that favorable or cause for concern?

Several air quality indices are listed in Table 2, along with brief comments about their construction. This list is intended to be representative, not exhaustive. These indices vary markedly in data requirements, complexity, and utility and thus well illustrate the lack of uniformity that prevails today among them.

The MAQI and the EVI proposed by the Mitre Corporation and the ORAQI developed at the Oak Ridge National Laboratory all relate measured levels of pollution to the federal air quality standards. For both MAQI and EVI a larger value implies greater pollution, with a value of 1.00 representing compliance with the standard. The MAQI is an index of average conditions during a one-year period, whereas the EVI is an indicator of the frequency of excursions over the short-term standards. ORAQI was developed for short term (e.g., daily) reporting purposes and is formulated mathematically such that a value of 10 corresponds essentially to unpolluted air and a value of 100 corresponds to pollutant concentrations equal to the federal standards.

Table 2

Representative Air Quality Indices

Index;Origin	Rationale	Users;Uses
MAQI;Mitre Corporation	SO_2, NO_2, TPM (others if stds. exist) are measured. Concentrations ratioed against secondary stds.; geometric mean computed.	CEQ; monthly, quarterly, or annual reporting using 12 months of data.
EVI;Mitre Corporation	SO_2, NO_2, TPM (others if stds. exist) are measured. For each, accumulate no. of excursions above secondary stds., divide by corresponding std.; geometric mean computed.	CEQ; monthly or quarterly reporting using 12 months of data.
ORAQI;Oak Ridge National Laboratory	SO_2, NOX, CO, TPM, OX measured. Formulated so that 10=background and 100=std. levels.	Local news media throughout nation; daily reporting.
AQI; New Jersey State Department of Environmental Protection & Bureau of Air Pollution Control	Measure max. 1 hr. avg. during 24 hr. period; for CO & OX; 24 hr. avg. for SO_2 & TPM. Defined such that: "Unhealthful," primary std. exceeded; "Unsatisfactory," "Satisfactory," "Good," related to secondary stds.	Communities in entire state; daily reporting in news media.
API:NYC Environmental Protection Administration	SO_2, COH, NO_2 measured 24-hr.; CO measured 8-hrs., OX measured 1-hr. Worst pollutant establishes one-word description: "Good," "Acceptable," "Unsatisfactory," "Unhealthy," and "Significant Harm."	General population; daily reporting through news media.
API:WZZN (Radio/TV) Grand Rapids and Muskegon, Michigan	TPM measured 3-½ hrs. daily at downtown site; data scaled 0-100 and labeled Very Low, Low, Moderate, High, or Very High.	Local news media; daily reporting.
AQI:Puget Sound Air Pollution Control Agency	Measure 24-hr. avg. SO_2, TPM, measure wind speed and direction; SO_2, COH, and (SO_2 x COH) are scaled; highest value them becomes the daily value.	General public in 3 metropolitan areas; daily reporting.

Table 2 (continued)

Index;Origin	Rationale	Users;Uses
API:Atlanta, Georgia	24-hr. avg. TPM, SO_2, CO measured. Comparison ratio with stds. averaged into single number.	General public; daily reporting
API and Alert System; Ontario Department of Energy and Resources Management	24-hr. avg. SO_2, COH measured and then scaled. First Alert @ 50; Second Alert @ 75; Third Alert @ 100.	Departmental use; not for general use.

Abbreviations

API	Air Pollution Index	MAQI	Mitre Air Quality Index
AQI	Air Quality Index	NO_2	Nitrogen dioxide
CEQ	Council on Environmental Quality	ORAQI	Oak Ridge Air Quality Index
CO	Carbon monoxide	OX	Oxidant
COH	Coefficient of haze	SO_2	Sulfur dioxide
EVI	Extreme Value Index	TPM	Total particulate matter

These three indices were used by the CEQ to compare air quality trends in several major cities during the years 1968-1970. Table 3 lists the index of values along with the ratios of the annual means of the concentration levels of sulfur dioxide, total suspended particulates and oxides of nitrogen to the concentrations specified by their corresponding primary standards. Although these five indices are constructed quite differently and for different applications, they indicate the same general trends.

Most air quality indices rely upon the federal air quality standards to scale and weight individual pollutants, but standards are needed that are compatible in time interval with measurement practices. More importantly, continued research on the health, ecological, and aesthetic effects of air pollution is essential. Nevertheless, a move toward uniformity in air quality indexing can and should be made now; future advances in standards, measurement techniques, weighting schemes, etc. can be incorporated as they emerge.

Table 3 - Comparative Values of Air Quality Indices For 10 Cities MAQI - EVI - ORAQI

Year	MAQI	EVI	ORAQI	Ratio of annual mean to EPA primary standards		
				SO_2	TSP	NO_x
Atlanta:						
1968	2.88	2.21	108	0.39	1.07	2.20
1969	2.51	1.10	91	.33	1.03	1.80
1970	2.60	3.44	86	.24	1.20	1.65
Detroit:						
1968	4.01	17.90	145	.83	1.79	2.44
1969	3.66	12.11	138	.69	1.55	2.25
1970	3.39	9.17	102	.45	1.51	1.69
St. Louis:						
1968	3.82	18.07	157	1.14	2.16	2.17
1969	5.35	27.24	163	.91	2.45	2.02
1970	4.41	13.15	125	.73	2.05	1.72
Milwaukee:						
1968	4.27	20.82	119	.48	1.85	2.05
1969	3.17	10.17	89	.20	1.47	1.69
1970	2.69	6.41	70	.19	1.61	1.21
New York:						
1968	6.07	20.06	246	3.00	1.56	2.87
1969	5.01	13.39	181	1.69	1.40	2.93
1970	3.43	7.38	116	1.91	1.64	1.45
Baltimore:						
1968	3.51	6.95	127	1.07	1.31	1.78
1969	3.28	4.48	117	.75	1.47	1.86
1970	4.17	15.15	114	.68	1.51	1.80
Birmingham:						
1968	5.09	26.67	135	.21	2.41	2.46
1969	4.25	22.41	107	.21	2.16	1.75
1970	5.05	16.13	76	.10	2.07	1.10
Boston:						
1968	2.35	3.24	84	.65	1.24	1.01
1969	2.51	2.58	79	.80	1.13	.75
1970	2.12	1.09	76	.59	1.07	.96
Washington, D.C.:						
1968	NA	NA	NA	NA	1.15	NA
1969	1.51	0	NA	.30	.97	1.29
1970	1.52	0	NA	.34	1.03	1.15
Philadelphia:						
1968	3.84	9.15	128	1.13	1.49	1.65
1969	2.72	5.53	82	.88	1.63	NA
1970	3.99	15.32	150	1.05	1.80	2.28

Source: Third Annual Report of the Council on Environmental Quality, August 1972, pp. 10, 44.

4.3 Water Quality

Construction of water indices is similar conceptually to that of air indices but is more difficult in application for two main reasons.

First, the number of known pollutants in water exceeds that in air, and not all are expected to be found in all water bodies. Thus, the indexing method becomes quite involved, even without consideration of synergisms.

Second, no single use exists for water for which we can set standards, as we can for air because of our prime concern with its effect on human health. The federal Environmental Protection Agency considers water to have five separate, but not necessarily mutually exclusive, uses for which quality criteria can be established: recreation and aesthetics; public water supplies; fish, other aquatic life, and wildlife; agricultural use; and industrial use. The 1972 Water Quality Act Amendments set a goal of water quality sufficient to allow for water-contact recreation and the propagation of fish and shell fish. Thus, there is no single criterion to form the basis of a water quality index.

In spite of the difficulties, several water indices are available, three of which are outlined here. As in the case of air indices, none has emerged as the one to be preferred for general use.

The National Sanitation Foundation solicited the opinions of 74 water quality experts about which variables were necessary to describe water quality, what relative weights should be assigned to each, and the relative indicator value of each variable as a function of its actual concentration in water. Using the iterative DELPHI technique, the experts narrowed the number of variables to eleven. The Foundation's

Water Quality Index (WQI) is calculated by summing nine of the variables' relative indicator values which are weighted as to relative importance. The Foundation further specified that if any pesticide or toxic element (the other two variables selected by the experts) exceeded its maximum allowable concentration, the WQI is assigned its most extreme value.

The Environmental Protection Agency devised a Prevalence-Duration-Intensity Index (PDI) to describe water quality for a specified water body for a particular use. Prevalence (P) is the length in miles along the water course or the shoreline of a lake over which the water quality standard for any variable is exceeded at least one time during the year. It does not matter how many variables exceed the standards or to what extent they are exceeded. Duration (D) is a measure of the temporal distribution of pollution over the year. This value is 0.4 if any standard is exceeded and increases to a maximum of 1.0 by increments of 0.2 for each additional quarter of the year in which pollution occurs. Intensity (I) indicates the severity of the pollution and ranges from 0 to 1. It represents the combined influence of pollution on the ecological system including man, economic value of the water resource, and aesthetic value of the water body.

The Pollution Index then is the product of P, D, and I. It also is possible to calculate an index of water quality for geographical areas where different water bodies have varying P, D, and I values. PDI data for nine major watersheds in the United States were published in the Third Annual Report of CEQ.

The Council on Environmental Quality contracted with Enviro Control, Inc., to analyze trends in water quality at 140 monitoring stations

throughout the nation. Rather than merely plotting the monitor readings, the contractor adjusted these data for the flow rates in the watercourses. Increased water flow dilutes the pollutant burden and reduces the concentration of the pollutant already in the watercourse. However, increased precipitation can wash additional pollutants into the watercourse, thus offsetting any dilution effect. The results of this procedure, published in the Third Annual Report of CEQ, show that in rural areas the increased runoff after precipitation increased the pollutant burdens as well as the flow rates, as was expected because most pollution in these areas originates from non-point sources. The surprising result was that increased flow rates in about three-fourths of the sampled areas characterized by high population density or by industrial activity did not reduce pollutant concentrations. That is, the additional pollutant burdens carried into the watercourses by runoff more than compensated for reductions in concentrations by dilution. These modified measures of water quality, then, tell us more than what is present in the water; they reveal that non-point sources in both urban and rural areas deserve more attention than we have been giving them.

Other indexing efforts for water quality are underway at various institutions. For example, a Consumers' Water Quality Index that takes into consideration the general public's attitudes about water quality has been developed in the Department of Environmental and Water Resources Engineering at Vanderbilt University; several modifications of the National Sanitation Foundation's WQI have been tailored for specific uses of water.

The diversity of indexing approaches discussed above suggests that much experimentation is needed before we can achieve a water index that

is suitable for all users, if indeed a single index is possible or desirable. The present indexing work also emphasises the real need that exists for indices to help resolve our current water quality problems and to plan for the decades ahead when the demands on our water resources will be greater still.

4.4 Land Use

The issues and policies important to land use are substantively and conceptually different than those important to air and water pollution and radiation. A fundamental problem related to measuring the impacts of various uses on land is the inadequate identification, on both a national and local scale, of key land use issues and policy choices toward which indices could be effectively designed. Much information is available on land in terms of its geological and geographical properties and its economic uses. Less is known about the biology of a landscape or its ecological carrying capacity or the fragility and resilience of ecosystems present. However, without clearly stated land use policies it is difficult to develop criteria or standards that can be used to compare changes in land use patterns in terms of national environmental goals.

Indices on the use, availability, and impacts of alternative uses, especially for urban purposes, are desirable. There is a large body of data on the use and availability of land which has been transformed into use measures. Indices gauging the impacts of land use on environmental quality present conceptual problems, however. For example, in the case of urban land, data are available on densities of population; number and type of industrial and commercial establishments; municipal services

such as schools, libraries, and post offices; green space and recreational areas, such as parks and playgrounds; transportation systems, and many other factors. But a method for translating these various data to a common scale or scales is not available. Appraisal of the relative importance of these factors depends largely on subjective personal and cultural values. In many cases where a conceptual framework exists for an objective weighting, the relative importance of the various factors is not known. A complicating factor is the status of land as a "commodity," contrasting drastically with the "common goods" status of other environmental features.

In the case of ionizing radiation, the rem is useful because all ionizing radiations affect living systems by means of similar bio-physical mechanisms for which the rem is a method of quantification. In contrast, humans are affected by land use in a multitude of ways, and no common denominator has as yet been identified. The development of useful indices to describe the impact of land use may be inherently more difficult than the development of indices for many other aspects of environmental quality.

Many different approaches will have to be explored if useful land use indices are to be developed. One of the approaches which may improve out understanding of the impact of alternative land use patterns is to measure the perceptions of individual members of the community. The term "perception" is used here broadly, encompassing not only immediate visual perception but also general awareness, attitudes, and values regarding the environment. Measures of environmental perception could have an important place in the development of environmental indices.

Perceived Environmental Quality Indices (PEQI) could be developed to assess aspects of environmental quality that intrinsically involve the interplay between the human observer and the environment. For example, a comprehensive set of land use indices could include measures of perceived environmental quality, such as the public appraisal of visual-aesthetic quality in the urban environment and of scenic quality of landscape in the non-urban environment. Standardized techniques can be used in the development of these PEQI, which will be especially useful in monitoring aspects of environmental quality for which physical measures are unavailable. PEQI can also aid in the selection of physical environmental indices by first identifying urban areas perceived by residents as being high and low in environmental quality and then determining the physical attributes that differentiate them.

Preliminary work on PEQI has been conducted on perception of: (1) air, noise, and water pollution; (2) landscape and scenic resources; (3) urban residential quality; (4) the quality of outdoor recreational facilities; (5) transportation systems; and (6) work and institutional environments (e.g., factories, hospitals, schools). Current efforts are fragmented among various fields and disciplines (e.g., environmental psychology, geography, natural resource management, architecture, and urban planning) and across various environmental categories (e.g., pollution, outdoor recreation environments, and urban residential environments). A state-of-the-art appraisal is needed to establish criteria for developing standard PEQI, to identify the properties of the observer as an environmental-quality-appraisal-instrument, to review the conceptual and methodological issues in using PEQI in conjunction with physical

environmental indices in policy and decision-making, to ascertain their role in communicating with the general public, and to consider the specific PEQI that could be appropriately aggregated into an index of environmental well-being.

The concept of "carrying capacity" may be appropriate as a basis for development of land use indices because it is related to the ability of land units to support life. Perhaps the only context in which that concept can effectively be applied for man is at the continental or global level. Biological productivity--in terms simply of food for man--may be affected not only by local soil or air pollution or loss of available soil nutrients (through erosion, siltation, or improper crop cultivation practices), but also by changes in global climate due to large-scale shifts in surface use of the earth (as by major reduction of forest land or by the spreading ofdeserts). The development of land use indices with ecological validity must therefore take into account not only the local aspects of land carrying capacities and the state of local environments, but also the overall land use patterns which have continental or global implications. Nonetheless, carrying capacity is a worthy concept for some land use indices.

While it would be desirable to monitor directly plant nutrients and other factors affecting biological productivity, surrogate data on such factors as crop yields, land values, and actual uses, can be relied upon. Additional work should be directed toward a fuller understanding of the ecological factors underlying use of land as the habitat of man.

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